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Age And Growth Of Weakfish, Cynoscion Regalis, In The Chesapeake Bay-Region With A Discussion Of Historical Changes In Maximum Size

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Abstract.—Weakfish, *Cynoscion regalis*, were collected in 1989–93 from commercial catches in the Chesapeake Bay region, and special collections of large fish were made in Delaware Bay. Ages were based on sectioned otoliths. Most weakfish were 200–600 mm TL and ages 1–4 years. Maximum age was 17 years from a 1985 Delaware Bay fish. Maximum current observed ages were 12 years in Chesapeake Bay and 11 years in Delaware Bay. However, fish older than age 6 were rare in both areas. There was no evidence that Delaware Bay fish reached a larger maximum size or maximum age than Chesapeake Bay fish. Although weakfish size was a poor predictor of age, weakfish growth was well described by the von Bertalanffy growth model (r^2=0.98, n=854). Maximum size and age has fluctuated in both Chesapeake and Delaware Bays over the past thirty years. In both areas the maximum size of fish, based on citation records, greatly increased from the late 1960's until the mid-1980's, as did the numbers of these large fish. These fluctuations appear to be due to a series of strong year classes, beginning in the late 1960's.

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Age and growth of weakfish, *Cynoscion regalis*, in the Chesapeake Bay region with a discussion of historical changes in maximum size*

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The weakfish, *Cynoscion regalis*, is a recreationally and commercially important sciaenid which ranges from eastern Florida to Massachusetts but is most abundant from North Carolina to New York (Mercer, 1985). Although believed to be resident year-round in the Carolinas, weakfish occur farther north only seasonally (Bigelow and Schroeder, 1953). In the spring, weakfish migrate northward and inshore to estuarine feeding and spawning grounds; this pattern is reversed in the fall (Wilk, 1979), and most fish are believed to overwinter off North Carolina (Pearson, 1932). Weakfish occur in Chesapeake Bay, roughly from April through November (Pearson, 1941; Massmann et al., 1958), where they support one of the region's most important fisheries (Rothschild et al., 1981).

Although weakfish have been important in Atlantic coast fisheries since the 1800's (Mercer, 1985), weakfish landings have fluctuated widely. Changes in maximum size and age have occurred concurrently with fluctuations in presumed abundance (Massmann, 1963; Joseph, 1972; Feldheim, 1975; Villoso, 1989). For example, in Chesapeake Bay, the largest reported weakfish was 16 lb (7.3 kg) in 1921 (Hildebrand and Schroeder, 1928). However, by the mid-1950's, when landings were low, mean size decreased and few fish weighed more than 2 lb (0.91 kg) (Massmann, 1963). Large fish again became common in Chesapeake Bay as the fishery recovered in the 1970's and early 1980's; a 19-lb (8.6 kg) weakfish was caught in Chesapeake Bay in 1983 (Mercer, 1985).

It is necessary to understand age structure and growth, and how they vary regionally and temporally, in order to gain insight into the causes of historical fluctuations in weakfish landings and abundance. Although there have been many studies on weakfish age and growth (e.g. Taylor, 1916; Nesbit, 1954; Perlmutter et al., 1956; Massmann, 1963; Merriner, 1973; Feldheim, 1975; Seagraves, 1981; Shepherd and Grimes, 1983; Hawkins, 1988), all have been based on scales which underage older fish of many species (Beamish and McFarlane, 1987),

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including weakfish (Lowerre-Barbieri et al., 1994). Thus, ages based on scales may lead to inappropriate growth and mortality estimates, which can affect yield modeling results and management decisions.

Weakfish age and growth have been reported to vary geographically, increasing with latitude (Pearson, 1932; Nesbit, 1954; Shepherd and Grimes, 1983). However, it is unclear whether these differences are due to different population segments (Nesbit, 1954; Perlmutter et al., 1956; Seguin, 1960) or to differential migration (Vaughan et al., 1991). Regardless of the cause, if these differences exist, estimates of growth and longevity throughout the weakfish range will be necessary for proper management. Weakfish age and growth in the Chesapeake Bay region have not been examined since Massmann (1963). A current study is necessary because changes in landings and maximum size and age suggest that weakfish age structure may have changed.

This study was undertaken to determine the current age structure and growth of weakfish in the Chesapeake Bay region, by using a validated ageing method (Lowerre-Barbieri et al., 1994). The hypothesis that weakfish in the Chesapeake Bay region reach a lower maximum size and age than weakfish in Delaware Bay (Shepherd and Grimes, 1983) is evaluated, as are historic trends in maximum size and abundance of large fish (≥3.6 kg, or ≈8 lb) in Chesapeake and Delaware Bays.

Methods

A total of 4,137 weakfish were collected in 1989–92 from pound-net, haul-seine, and gillnet fisheries in the Chesapeake Bay region. On each sampling date either a 22.7 kg (50 lb) box of each available market grade (fish large enough to be sold for human consumption, graded as small, medium, or large) or the total catch was purchased and processed for biological data. Because boxes could not be randomly selected, our size and age compositions were not expandable to the overall fishery. However, Chittenden (1989a) found little or no variation in fish size (total length) among boxes, within grades. To obtain year-round samples, 344 fish were collected in winter (when weakfish do not occur in Chesapeake Bay: Pearson, 1941; Massmann et al., 1958) from the trawl fishery operating in Virginia and North Carolina shelf waters north of Cape Hatteras. Since age-1 fish are not fully recruited to market grades (see Size and Age Composition heading in Results section), an additional 200 age-1 and young-of-the-year fish were collected by the Virginia Institute of Marine Science (VIMS) juvenile trawl survey from May to August 1990–92 in Chesapeake Bay. Details on sampling design and gear of the VIMS survey can be found in Chittenden (1989b) and Geer et al. (1990).

To increase the number of large fish in this study for comparison of maximum size and age in Chesapeake and Delaware Bays: 1) 35 fish were collected from the 1992 World Championship Weakfish Tournament in Dover, Delaware; 2) 10 fish (≥3.6 kg total weight) from Delaware Bay and 5 fish (≥3.6 kg total weight) from Chesapeake Bay were collected from commercial catches in 1992 and 1993; and 3) 41 fish (≥500 mm total length) taken in Delaware Bay in 1985 and 1986 by Villoso (1989) were included in the analysis. Fish ≥3.6 kg (≈8 lb) or ≥500 mm total length (TL) were targeted because these fish were beyond the range common in our regular Chesapeake Bay samples (see Size and Age Composition heading in Results section). To evaluate historic trends in maximum size and abundance of large fish, the annual number of citation-size fish and the total weight (TW) of the largest fish reported were obtained from the Virginia Saltwater Fishing Tournament (1958–92) and from the Delaware State Fishing Tournament (1968–92). Citation-size fish are large and rare enough to be considered trophy fish. Citation size may change if larger fish become more numerable (e.g. weakfish citation size has fluctuated from 1.8 to 5.5 kg in the Chesapeake Bay over the past 25 years).

In general, collections were processed for biological data as follows: fish were sexed, measured for TL (nearest mm), total gutted weight (TGW, nearest gram), and gonad weight (GW, nearest gram). Gutted weights included GW and were used (rather than total weights) because weakfish are piscivorous and can swallow fish a third of their own weight, a characteristic that could greatly bias somatic weights (Lowerre-Barbieri, 1994). Somatic weight (SW) was calculated as TGW minus GW.

Otoliths from 3,290 fish were sectioned and aged by using the validated method described in Lowerre-Barbieri et al. (1994). Of 1,191 otoliths read by two separate readers, 99.8% of the assigned ages agreed. In addition, otolith annuli did not show severe crowding at older ages and were easily distinguished (even in a 17-year-old, the oldest fish aged [Fig. 1]). More than 95% of the fish sampled were aged each year except 1990. In 1990, when many small fish were sampled, those to be aged (794 out of 2,098) were selected by systematic subsampling. Ages were assigned assuming 1 January as an arbitrary birthdate (Jearld, 1983; Shepherd, 1988). This birthdate was selected so that fish of the same year class collected in April and May—before annuli form (Lowerre-Barbieri et al., 1994)—would be assigned the same age as those collected after annuli had formed.

To determine whether the population growth rate was representative of the true growth rate (i.e. whether there was not size-selective mortality within year classes), size at first annulus formation was evaluated for sectioned otoliths from fish ages 1–12 (Ricker, 1975). Otolith radius to the first annulus (distance from the nucleus to the proximal edge of the first annulus) was measured by using a Via-100 camera and monitor system with a dissecting microscope at 24× (Lowerre-Barbieri et al., 1994). Measurements were taken on 403 Chesapeake Bay fish collected in 1989 and 1992–93 and on 47 Delaware Bay fish from 1992 to 1993. Given the strong relationship between otolith radius and fish total length (Lowerre-Barbieri et al., 1994), size of the otolith at the first annulus was considered an indicator of fish size at age 1. A one-way analysis of variance (ANOVA) was used to determine whether otolith size at first annulus was significantly different by age.

Growth was evaluated by using nonlinear regression (Marquardt method) to fit the von Bertalanffy model (Ricker, 1975) to observed, individual lengths of Chesapeake Bay fish ages 1–12. To remove seasonal effects, only fish collected in April and May were used for calculations. These months are the period when 1) somatic growth rate increases; 2) otolith annuli form; and 3) the largest range of sizes and ages occur in Chesapeake Bay. Finally, to examine differences in growth by sex, observed mean size at age in Chesapeake Bay was calculated for each sex and compared by using a t-test.

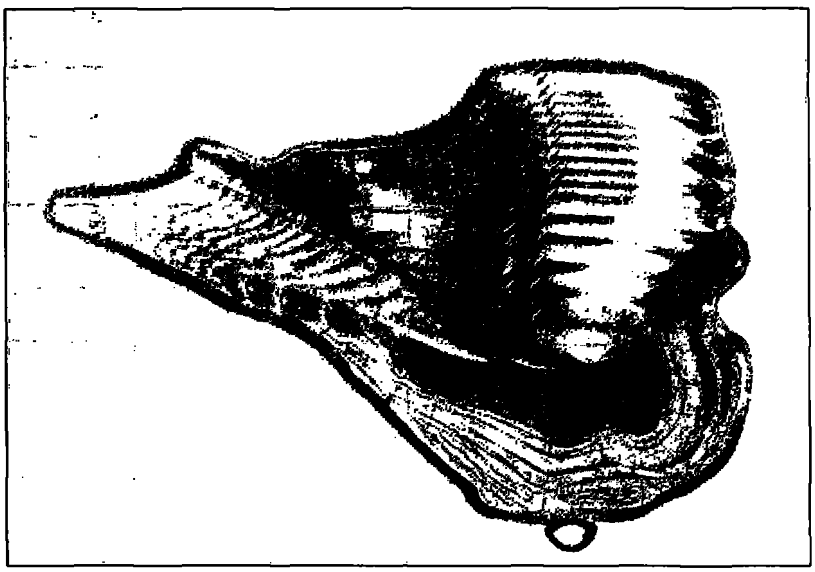

Figure 1

Transverse otolith section of an age-17 weakfish, *Cynoscion regalis*, caught in May 1985 in Delaware Bay. Arrows indicate annuli.

Linear regression was used to determine a SW-TL relationship on log-transformed data from fish collected in Chesapeake Bay. To include the greatest possible range of sizes (188–875 mm TL and 71–6,137 g SW), data were pooled over gears (pound nets, haul seines, and gill nets). A t-test was used to determine if the slope of the SW-TL regression was significantly different from 3—a slope of 3 indicating isometric growth. When only TL was given in the historic literature, conversions were made by using a TGW-TL relationship based on fish collected in April and May in Chesapeake Bay 1989–93, ranging from 20 to 6,276 g TGW and from 140 to 875 mm TL. This same relationship was used to estimate TL for citation-size fish.

All data were analyzed by using statistical methods available in SAS (1988). Model assumptions were evaluated by examination of residuals (Draper and Smith, 1981). Rejection of the null hypothesis was based on an α level of 0.05, unless otherwise noted, and F-tests in ANCOVA were based on type III sums of squares (Freund and Littell, 1986).

Results

Size and age composition

Most weakfish collected from Chesapeake Bay commercial fisheries during 1989–92, excluding those targeted for their large size, were 200–600 mm TL (98%) and ages 1–4 years (97%). However, observed sizes ranged from approximately 200 mm TL to 850 mm TL, and observed ages ranged from 1 to 8 years (Fig. 2). The smallest fish (≈200 mm TL) collected from market grades were similar each year. However, the largest observed fish varied from approximately 650 mm TL in 1990 to 850 mm TL in 1989 and 1992. In 1990, a larger percentage (78%) of small (<300 mm TL), young weakfish were collected and no fish were older than age 5 (Fig. 2). Most of these small fish (<300 mm TL) were collected by haul seine and pound net (Fig. 3), whereas gill nets caught fish primarily in the 300–400 mm TL range.

Weakfish were not fully recruited to market grades until age 2. Young-of-the-year and yearling fish occurred in Chesapeake Bay, making up 99% (n=200) of the fish analyzed from the VIMS juvenile trawl survey. However, young-of-the-year fish were not present in market grades, and yearlings were not fully recruited, as evident by their low frequency in annual age compositions (Fig. 2).

Older, larger weakfish occurred in Chesapeake Bay primarily in the spring, when they appeared to arrive before younger fish. Fish age 4 and older occurred in the spring in relatively large numbers, making up 51% and 27% of April and May samples (1989–92), respectively (Fig. 4). However, few fish older than age 4 were sampled after May, and they never made up more than 8% of the fish observed in later months. In contrast, few age-1 fish were observed in either market grade samples or in the VIMS trawl survey until June, after which they made up roughly 30% of the market grade fish sampled.

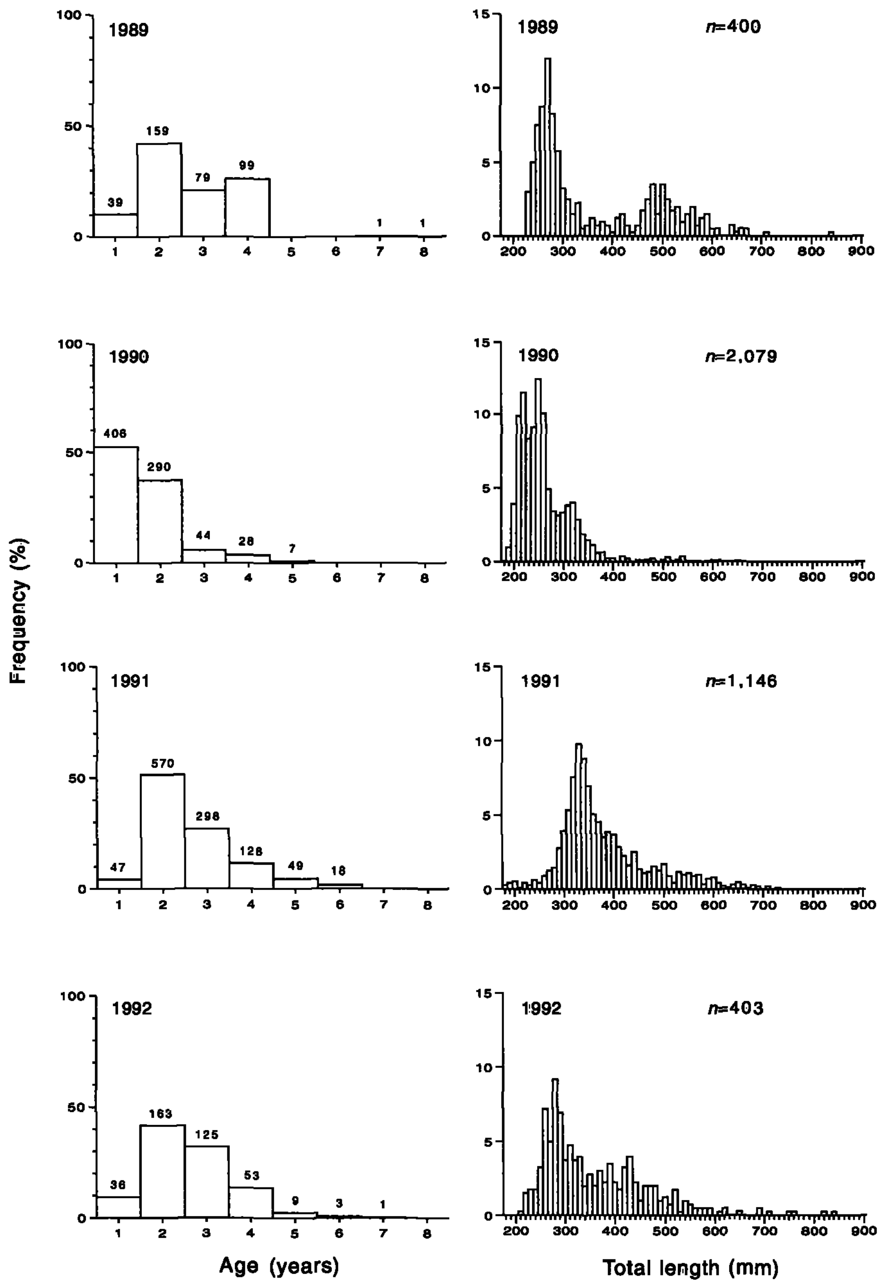

Figure 2

Age and length frequencies of Chesapeake Bay weakfish, *Cynoscion regalis*, by year (1989–92) pooled over gears. Sample sizes are indicated above each age. Total annual sample size is noted for lengths.

Mean monthly size at age also differed seasonally. Mean size at ages 3–6 of Chesapeake Bay fish collected in April and May, 1989–92, were larger than those collected in August and September (Table 1). In 1992, mean monthly TL of age-2 and age-3 fish (the most abundant ages in the samples) decreased steadily from April through July (Fig. 5). Although the pattern was less clearly defined in other years, a decrease in mean TL for the observed age-3 fish from April to June was evident. The mean TL of age-2 fish also declined from April to May in 1991 and 1992.

There was no evidence that weakfish from Delaware Bay reached a larger maximum size or age than those in Chesapeake Bay. Maximum observed age of Chesapeake Bay fish was 12. However, annual observed maximum age of fish not selected for their large size varied: 8 in 1989 (n=378), 5 in 1990 (n=775), 6 in 1991 (n=1,110), and 7 in 1992 (n=391). Maximum observed age in Delaware Bay was 11. Fish older than age 6 were rare in both regions. Only four fish ≥3.6 kg were collected in 1992 in Chesapeake

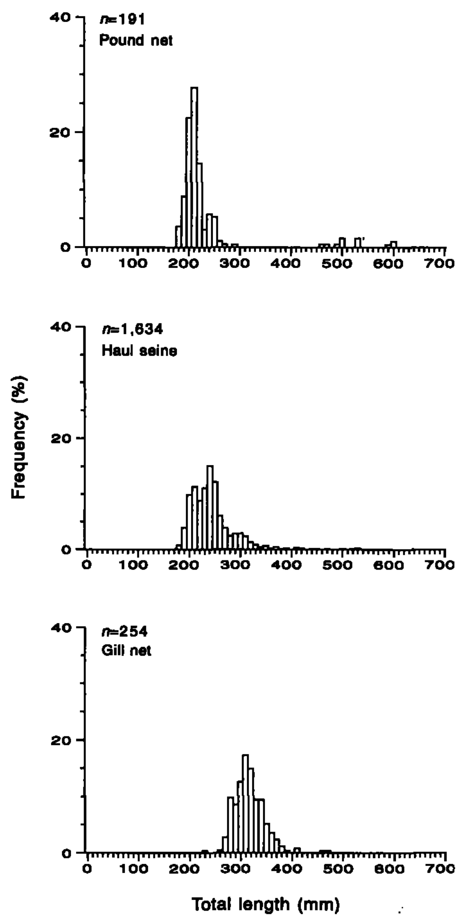

Figure 3
Length frequencies of Chesapeake Bay weakfish, *Cynoscion regalis*, by gear in 1990.

Table 1
Mean total length (TL) at age for Chesapeake Bay weakfish, *Cynoscion regalis*, collected in April–May and August–September, 1989–92.

Age	*n* April–May	Mean April–May	*n* Aug–Sep	Mean Aug–Sep
1	89	176	311	251
2	246	311	516	312
3	246	411	119	402
4	213	511	50	507
5	46	558	8	549
6	13	631	2	626

Bay—three age 6 and one age 10. In Delaware Bay in 1992, seven fish were collected—one age 4, one age 5, four age 6, and one age 8. An additional six fish ≥3.6 kg were collected at the 1992 World Championship Weakfish Tournament in Delaware, all age 6. In 1993, only four fish ≥3.6 kg were collected—one age-12 fish from Chesapeake Bay, and three fish from Delaware Bay, ages 6, 8, and 11. Maximum TL observed in both regions was 875 mm. Maximum TGW was 6.3 kg in Chesapeake Bay and 6.6 kg in Delaware Bay. Ten fish collected from Delaware Bay >age 8 were similar in size to the two fish collected in Chesapeake Bay (See Fig. 7 below).

Growth

Weakfish size (TL) was a poor predictor of fish age. Ages 1 and 2 were the only groups which did not have overlapping size distributions (Fig. 6). In contrast, TL's of fish (ages 2–5) collected in April and May, showed broad ranges, much overlap, and multiple modes (Fig. 6). A fish 350 mm TL or 350 g TGW (Table 2) could potentially be any of these ages (2–5).

Observed size at age was used to estimate weakfish growth, because there was no evidence of size-selective mortality. Mean size at first annulus showed no consistent pattern with increasing age (Table 3), and no significant differences were found between sizes at first annulus by age (n=540, F=1.75, P=0.06).

Weakfish growth was well described by the von Bertalanffy model (Fig. 7). The von Bertalanffy curve was calculated for pooled sexes because weakfish show no readily observed sexual dimorphism. Although lengths at age were similar for both sexes, mean TL's at age were usually larger for females than for males, and significantly so for ages 2 and 3 (Table 4). Mean observed TL's of pooled male and female Chesapeake Bay weakfish in April and May were 176, 311, 412, 510, 558, and 631 mm for ages 1–6, respectively. Despite the high variability in size at age, observed lengths at ages 1–12 showed a good fit (r^2=0.98) to the von Bertalanffy model (Fig. 7). The model's estimated parameters, asymptotic standard errors, and 95% confidence intervals fell within a reasonable range, given the observed data (Table 5).

Although the SW-TL relationship of weakfish collected in Chesapeake Bay differed significantly by sex (ANCOVA, P<0.05), the equations (male $SW=9.1\times10^{-6}\ TL^{3.1}$ and female $SW=6.9\times10^{-6}\ TL^{3.05}$) and coefficients of determination (r^2=0.99) were similar for both sexes. Therefore, an equation for pooled sexes was calculated (Fig. 8):

$$SW = 6.0 \times 10^{-6} TL^{3.04}\ (r^2=0.99,\ n=3{,}742).$$

The slope (b=3.04, SE=0.005) was not significantly different from 3 (t-test, t=0.002, P>0.05) indicating

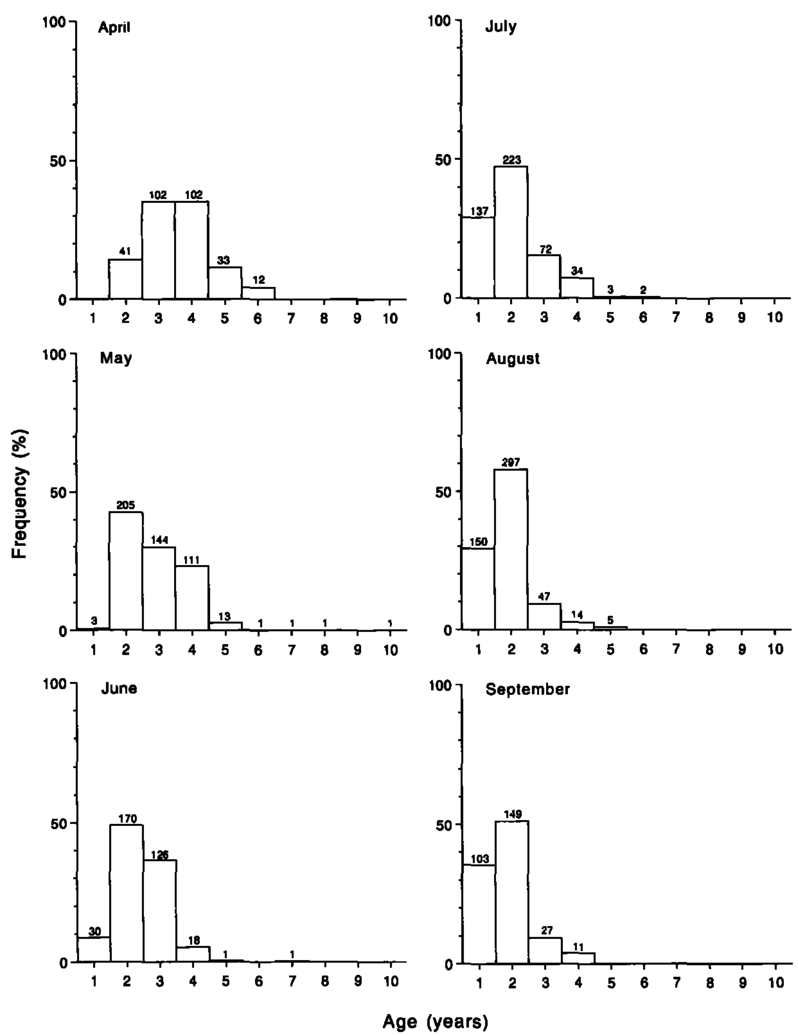

Figure 4
Age-frequency distributions of Chesapeake Bay weakfish, *Cynoscion regalis*, by month, pooled over the years 1989–92. Sample size is indicated above each bar.

isometric growth. The TGW to TL relationship for April and May was

$$TGW = 4.7 \times 10^{-6} TL^{3.13}\ (r^2{=}0.99,\ n{=}950).$$

Historic trends in maximum size and age

Older weakfish were collected in Delaware Bay in 1985–86 than in 1992–93. The mean age of fish ≥3.6 kg in 1985–86 was 9.6 years, significantly higher than that in 1992–93 (6.4 yr; t=3.14, n=26, P<0.05). Of the 10 fish ≥3.6 kg in 1985–86, one was age 4, one age 6, two age 8, two age 9, one age 11, two age 12, and one age 17. In contrast, the maximum age observed in 1992–93 was only 11, and of the 16 fish ≥3.6 kg only three of them were older than age 6.

Maximum sizes of weakfish began to increase in Chesapeake and Delaware Bays in the early 1970's, concurrent with the recovery of the weakfish fishery. From 1958 to 1968, the largest weakfish reported to the Virginia Saltwater Fishing Tournament was 3.1 kg (662 mm TL, Fig. 9). Similarly, the largest fish caught in Delaware Bay in 1968 and 1969 (when citation records began) was 2.6 kg (626 mm TL). However, in 1970 maximum size in Chesapeake Bay was >3.1 kg (662 mm TL) for the first time since 1958, and maximum size in Delaware Bay increased from

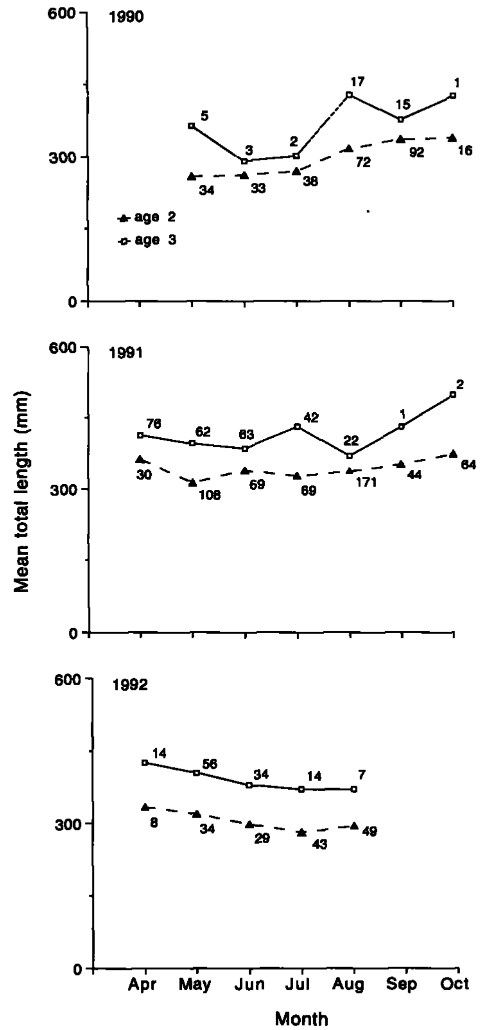

Figure 5

Mean monthly total lengths at age 2 and 3 of Chesapeake Bay weakfish, *Cynoscion regalis*, 1990–92. Sample size is indicated next to each point.

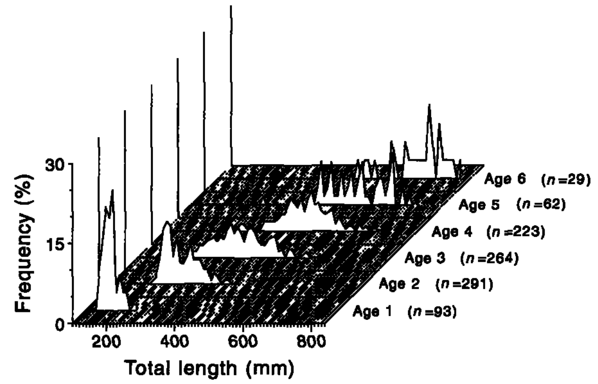

Figure 6

Length frequencies at age for weakfish, *Cynoscion regalis*, collected in April and May 1989–92, pooled over gears and locations.

Table 2

Mean total gutted weights (TGW), range and standard errors at age for Chesapeake Bay and Delaware Bay weakfish, *Cynoscion regalis,* collected in April and May, pooled over gears, 1989–93.

Age	*n*	Mean (g)	Range (g)	Standard error
1	91	49	20–161	2.4
2	285	310	113–1,038	10.3
3	263	778	160–2,099	28.3
4	223	1,494	342–3,866	37.4
5	62	2,126	284–4,031	105.0
6	29	3,268	1,507–5,360	197.3
7	1	3,257	—	—
8	4	5,230	3,370–6,475	591.5
9	1	5,311	—	—
10	1	6,260	—	—
11	1	6,190	—	—
12	1	6,276	—	—

2.6 kg (626 mm TL) in 1969 to 3.9 kg (712 mm TL) in 1970. By 1973 maximum weight had more than doubled, compared with that in the late 1960's, with 6.4 kg (834 mm TL) in Virginia and 5.9 kg (813 mm TL) in Delaware. Maximum sizes continued to increase until 1985 and remained high until 1989 in Virginia and 1990 in Delaware.

The abundance of large fish in Chesapeake and Delaware Bays also increased in the early 1970's, concurrent with the increase in maximum size. From 1958 to 1968, only 64 fish >1.8 kg (556 mm TL) were reported in Virginia (Fig. 10). Similarly in 1968 and 1969, only 13 fish >1.4 kg (513 mm TL) were reported in Delaware Bay. However the number of fish >1.8 kg (556 mm TL) reported in Virginia increased from 2 in 1969 to 83 in 1970. Similarly, in Delaware Bay, the number of fish >1.4 kg (513 mm TL) increased from 12 in 1969 to 121 in 1970. By 1980, 1,399 fish >5 kg (771 mm TL) received citations in Virginia, and 1,229 fish >4.6 kg (751 mm TL) received citations in Delaware.

Both Chesapeake and Delaware Bay have recently shown a marked decrease in maximum size and abundance of large weakfish. The number of large

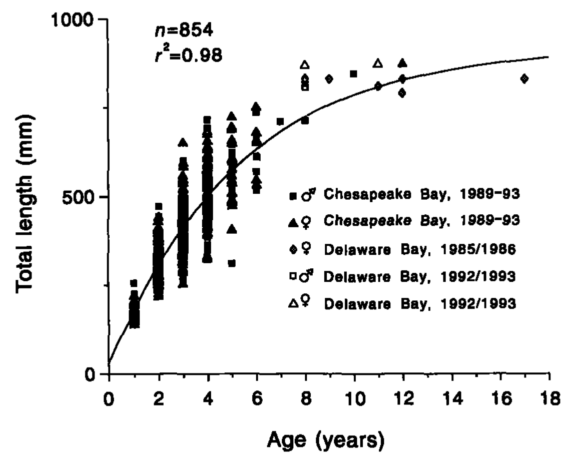

Figure 7

Observed lengths at age and fitted von Bertalanffy regression line for Chesapeake Bay weakfish, *Cynoscion regalis*, in April and May and for three fish from Delaware Bay. Weakfish in the asymptotic size range collected in Delaware Bay are included as reference points but were not used in calculations.

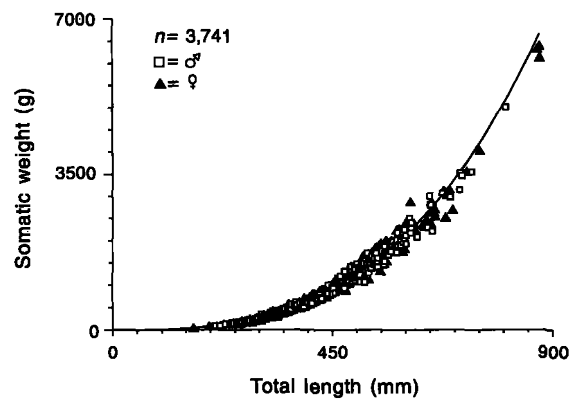

Figure 8

Somatic weight-length relationship of weakfish, *Cynoscion regalis*, in the Chesapeake Bay region, 1989–93.

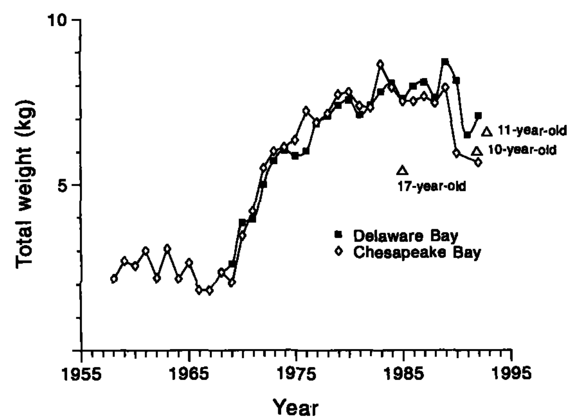

Figure 9

Maximum total weights of weakfish, *Cynoscion regalis*, reported in the Delaware Sport Fishing Tournament and the Virginia Saltwater Fishing Tournament, 1958–1992. The oldest and two heaviest fish from the present study are included as reference points.

Table 3

Mean, range, and standard error of otolith sizes at first annulus (mm) for weakfish, *Cynoscion regalis*, ages 1–12 (no age-9 fish were collected) from Chesapeake Bay and Delaware Bay.

Age	*n*	Mean (g)	Range (g)	Standard error
1	111	0.84	0.61–1.09	0.010
2	167	0.86	0.61–1.09	0.007
3	137	0.83	0.61–1.15	0.009
4	76	0.84	0.64–1.06	0.010
5	24	0.85	0.59–1.08	0.022
6	18	0.88	0.73–1.20	0.025
7	1	0.80	—	—
8	3	0.80	0.76–0.88	0.038
10	1	0.67	—	—
11	1	0.84	—	—
12	1	0.90	—	—

fish reported in Virginia dropped sharply in 1981 and has remained low. Only 12 fish >5.45 kg (792 mm TL) were reported in 1989 and 1990, no fish in 1991, and 3 fish >5.0 kg (771 mm TL) in 1992. During 1990–92, maximum size in Virginia was below 6 kg (817 mm TL) for the first time since 1972. Delaware Bay reported large numbers of fish >4.6 kg (751 mm TL) until 1989. However, the number of fish >5.0 kg (771 mm TL) decreased from 981 in 1989 to 11 in 1990. Only 18 fish have been reported since 1990. In 1991, maximum size of Delaware Bay fish dropped below 7.5 kg (878 mm TL) for the first time since 1981, and remained low in 1992.

Discussion

Size and age composition

Most weakfish in Chesapeake Bay in 1989–93 were 200–600 mm TL and ages 1–4, but fish as old as age

Table 4

Mean total length (mm) at age by sex of male and female weakfish, *Cynoscion regalis*, from Chesapeake Bay in April and May 1989–92, and *t*-test results ($\alpha = 0.05$, * = $P < 0.05$).

Age	Mean TL males	*n*	Mean TL females	*n*	*t*-value	Significance
1	176.3	42	175.9	47	0.14	NS
2	295.8	76	318.3	170	3.33	*
3	376.5	70	425.7	174	5.10	*
4	501.8	100	518.0	112	1.67	NS
5	553.9	24	562.5	22	0.37	NS
6	735.0	7	752.0	6	0.40	NS

Table 5

Von Bertalanffy model parameter estimates, standard errors and 95% confidence intervals estimated for weakfish, *Cynoscion regalis*, in the Chesapeake Bay region collected in April and May 1989–93.

Parameter	Estimate	Standard error	95% confidence intervals
L_∞	918.89	58.09	804.87–1032.91
K	0.19	0.02	0.15–0.24
t_0	–0.13	0.09	–0.29–0.04

12 and as large as 875 mm TL were observed. Population size and age compositions could not be estimated from our samples, because they were not randomly selected and came from several gear types. However, our samples should represent the population range. Hildebrand and Schroeder (1928) reported a similar size range (76–838 mm TL, n=280) in the 1920's. However, Massmann (1963) reported most weakfish in the 1950's were <300 mm TL, with a maximum size of 445 mm TL (n=14,516) and a maximum age of 5.

Chesapeake Bay weakfish are fully recruited to market grades by age 2. Joseph (1972) also reported age 2 as the first age fully recruited to the Chesapeake Bay pound net catch. However, yearlings sometimes make up a large portion of the commercial catch, as we observed in 1990, and clearly are vulnerable to the gear—especially pound nets and haul seines. Such small, young fish are often sold as scrap and do not show up in market grades. McHugh (1960) found weakfish to be the second most important food fish in scrap from the Chesapeake Bay pound-net fishery, and Massmann (1963) reported the number of weakfish in pound-net scrap often exceeded that in market grades. Thus, although Chesapeake Bay weakfish are fully recruited to market grades at age 2, age at recruitment to pound nets and haul seines is younger.

Large, older weakfish occur seasonally in Chesapeake Bay. From 1989 to 1992, older fish (ages 4 and older) were relatively abundant only in April and May. Hildebrand and Schroeder (1928) and Massmann (1963) also reported seasonal availability of large weakfish in Chesapeake Bay. Although Massmann (1963) collected few weakfish >2 lb (0.91 kg) or age 4, the largest fish in his study (2- and 3-year-olds) were relatively more abundant in April and May, similar to the present study. However, Hildebrand and Schroeder (1928) reported weakfish >3 lb (1.36 kg) to be more common in both spring and late fall. Thus, although large fish occur regularly in the spring, their appearance in the fall may be variable.

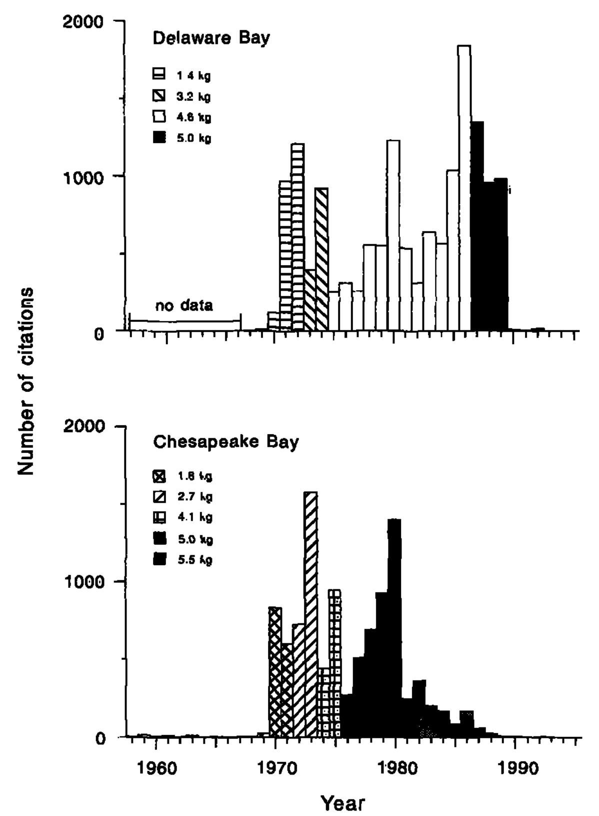

Figure 10

Number of weakfish, *Cynoscion regalis*, citations reported in the Delaware Sport Fishing Tournament and the Virginia Saltwater Fishing Tournament, 1958–92. Minimum citation weights are indicated by year. In 1972, the Delaware citation weight changed mid-year from 1.4 to 2.3 kg.

Age compositions of weakfish in Chesapeake Bay commercial catches are affected by migration. The pattern found in this study—of older fish arriving in Chesapeake Bay in April and May and then apparently leaving approximately when yearlings arrive—was also reported by Nesbit (1954) and Massmann (1963). This pattern indicates that Chesapeake Bay catches at any one time do not accurately represent relative weakfish abundance at age in the Bay. It is not known whether the old fish that occur in Chesapeake Bay originated there, nor is it known where they go after leaving the Bay. It has been reported that some weakfish that spend their younger years in Chesapeake Bay migrate farther north as they grow older, and that large fish are more abundant farther north (Pearson, 1932; Nesbit, 1954; Perlmutter et al., 1956). The location of large fish may also vary from year to year. For example, fish ≥age 4 made up only 4.5% of our 1990 Chesapeake Bay samples but 17.1% and 17.6% of the 1991 and 1992 samples, respectively.

The occurrence of a 17-year-old fish suggests past estimates of weakfish longevity and natural mortality may need to be reevaluated. The maximum age previously reported was age 12 (Shepherd, 1988). However, all former maximum ages were based on scales, which underage weakfish older than age 6 (Lowerre-Barbieri et al., 1994). The 17-year-old was aged as 7 by using scales (Villoso, 1989)—suggesting older fish may have occurred in the late 1970's and early 1980's but were underaged. The occurrence of a 17-year-old seems to indicate weakfish are longer-lived and experience lower natural mortality than previously believed, given the relationship between longevity and natural mortality (Hoenig, 1983; Gulland, 1983; Vetter, 1988).

Growth

Adult weakfish size at age showed a large range and much overlap. Broad size-at-age distributions have been reported for weakfish and attributed to the long spawning season from May through August (Welsh and Breder, 1923; Massmann et al., 1958; Thomas, 1971; Chao and Musick, 1977). An extended spawning season affects size at age in two ways: 1) true age at first annulus deposition varies from 7 to 12 months, depending on birthdate; and 2) fish born in different months encounter different environments, e.g. temperature, salinity, and prey availability, which affect larval growth (Goshorn and Epifanio, 1991) and mortality rates (Thomas, 1971). In addition, spawning pulses may result in several distinct size groups or modes within juvenile size distributions (Massmann et al., 1958; Thomas, 1971).

Delaware Bay fish did not demonstrate a greater longevity or maximum size than Chesapeake Bay fish in 1992–93. Maximum age was 11 in Delaware Bay and 12 in Chesapeake Bay. Maximum size in both regions was 875 mm TL. This is in contrast to Shepherd and Grimes' (1983) hypothesis that weakfish show different regional patterns, longevity and growth being lowest in the South Atlantic region, intermediate in the Chesapeake Bay region, and highest in Delaware Bay and northward. Shepherd and Grimes (1983) observed a maximum age of 11 (810 mm TL) in the northern region and 6 (710 mm TL) in the Chesapeake Bay region. However, they sampled the two regions differently. Samples representing the Chesapeake Bay region came only from a NMFS groundfish trawl survey along the Atlantic coast, whereas sampling in more northern regions included commercial fisheries within Gardiners Bay, New York; Sandy Hook Bay, New Jersey; and Delaware Bay. Because large fish are able to avoid trawls (Gunderson, 1993), estimates of maximum age may have been inaccurate owing to their sampling method (Hawkins, 1988). The Virginia Saltwater Fishing Tournament data show that more than 1,000 fish >5 kg (771 mm TL) were captured in 1980, indicating that large fish did occur in the area.

Recent studies have reported similar asymptotic lengths for weakfish throughout their range. Our estimate of L_∞ (919 mm TL) is comparable to recent estimates from different regions: 893 mm TL from Delaware Bay (Villoso, 1989) and 917 mm fork length from North Carolina (Hawkins, 1988). In contrast, Shepherd and Grimes (1983) reported much lower L_∞ estimates for the Chesapeake Bay region (686 mm TL) and North Carolina (400 mm TL).

Differential migration by size is an alternative explanation for the reported higher abundance of large, presumably older weakfish in the northern end of the range (Pearson, 1932; Nesbit, 1954; Perlmutter et al., 1956). Because swimming speed is a function of body size (Moyle and Cech, 1988), larger weakfish would be expected to travel faster and farther than smaller fish in a given amount of time. If weakfish constitute a single coastwide stock, as genetic research suggests (Crawford et al., 1988; Graves et al., 1992), and most fish overwinter off North Carolina (Pearson, 1932; Hawkins, 1988), then larger fish would arrive in northern estuaries before smaller ones in the spring. This is the pattern observed in Chesapeake Bay (Hildebrand and Schroeder, 1928; Massmann, 1963; the present study) and Delaware Bay (Feldheim, 1975; Villoso, 1989). In addition, because larger fish would travel farther north, they would be more abundant at the northern end of the weakfish range, thus causing a size-dependent distributional pattern similar to that reported for Atlantic menhaden, *Brevoortia tyrannus* (Ahrenholz et al., 1987).

The complex spatial and temporal distribution of weakfish may also affect estimates of seasonal growth. Growth of temperate-water fish usually follows the seasonal cycle; it is faster in summer and slower in winter (Moreau, 1987). Juvenile weakfish have been shown to grow rapidly during June–September (Mercer, 1985). However, mean size at age for Chesapeake Bay weakfish ages 3–6, was smaller in fall-caught than in spring-caught fish (Nesbit, 1954, the present study). Thus, it may be difficult to follow seasonal growth patterns in Chesapeake Bay commercial catches.

Historic trends in maximum size and age

The population structure of Chesapeake Bay weakfish has dramatically fluctuated since the 1920's. Hildebrand and Schroeder (1928) reported that most fish in Chesapeake Bay commercial catches weighed from 0.5 lb to 3 lb (0.23 kg to 1.36 kg) and that 6–10 lb fish (2.72–4.54 kg) were not uncommon. By the 1950's, however, Massmann (1963) reported that most fish were about 0.25 lb (0.11 kg) and few weighed more than 2 lb (0.91 kg). Massmann (1963) concluded that the uniformity in size structure from 1954 to 1958 indicated that there were no large fluctuations in year-class abundance; rather, he suggested that the weakfish population had stabilized at a low level of abundance. In 1970, however, the maximum size and number of large fish began to increase, peaking in 1980. Although the maximum size and number of large fish have declined recently, the current maximum size of 875 mm TL and maximum age of 12 remain well above those for the 1950's and 1960's (445 mm TL and age 5) (Massmann, 1963; Joseph, 1972).

Similar historic changes in maximum size and age have been reported over much of the weakfish range, with higher maximum ages and sizes during periods of higher landings and presumed abundance (Fig. 11). During the high landings of 1925–45, the maximum size was 865 mm TL (Nesbit, 1954), and maximum age was 8 (Perlmutter et al., 1956). However, during the 1950's and 1960's when landings were low, maximum size decreased to 760 mm TL and the maximum reported age was 6 years (Perlmutter et al., 1956). In the 1970's and 1980's, maximum size and age increased to 960 mm TL (Villoso, 1989) and 12 years (Shepherd, 1988), concurrent with increased weakfish landings. Because all previous ages were based on scales, the historic pattern of higher maximum ages during periods of higher landings are probably valid, even though actual ages may have been underestimated.

Citation data indicate an abrupt increase in maximum size and abundance of large weakfish in Delaware Bay in 1970 and in Chesapeake Bay in 1971. Maximum size rose steadily from 1970 to 1979 and then remained relatively constant until 1989 in both areas. Abundance of increasingly large fish (Fig. 10) also rose until 1980 in Chesapeake Bay and 1989 in Delaware Bay. Although these data have no estimates of effort associated with them, the general pattern appears accurate. Greater effort might increase the number of rare, large individuals being caught even if their abundance remained constant, but it would not be expected to cause such a dramatic change in the numbers and size of large fish being caught (i.e. in Chesapeake Bay no fish >3.5 kg TW from 1958 to 1969 to more than 1,000 fish >5 kg TW in

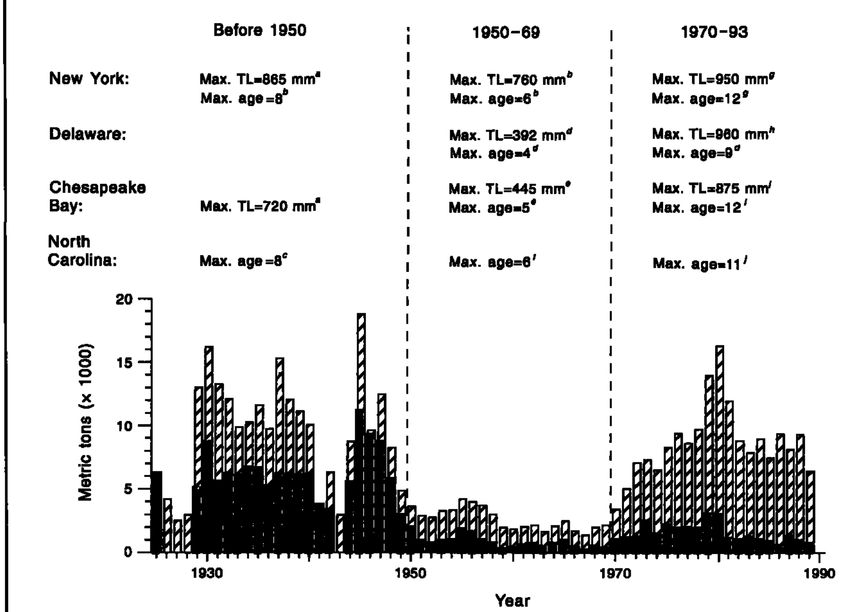

Figure 11

Commercial landings of weakfish, *Cynoscion regalis*, coastwide (hatched bars) and in Chesapeake Bay (black bars), 1925–89, with maximum reported sizes and ages (in years) for periods of high and low landings. Taken from: [a]Nesbit (1954), [b]Perlmutter et al. (1956), [c]Taylor (1916), [d]reported in Seagraves (1981), [e]Massmann (1963), [f]Merriner (1973), [g]Shepherd (1988), [h]Villoso (1989), [i]present study, [j]Hawkins (1988).

1980). In addition, citation-size fish have recently declined even though recreational effort has remained high.

The increased abundance of large, presumably older fish apparently reflects increased recruitment or year-class strength in the late 1960's. There is no evidence that fishing mortality decreased. In contrast, effort increased during this same period (Wilk, 1981), and peak regional landings shifted to North Carolina, where exploitation of smaller weakfish is higher than in more northern regions (Hawkins, 1988). The importance of fish born in the late 1960's is indicated by the increase of fish >1.8 kg (556 mm TL) in Chesapeake Bay and >1.4 kg (513 mm TL) in Delaware Bay in 1970 and 1971, respectively. Based on current TGW-at-age data (Table 2), the age of these fish would be 4–5 years, and they would have born between 1965 and 1967. By 1976, these fish would be 9–11 years old and >5 kg TGW. The stepwise increase in abundance of fish >5 kg in Chesapeake Bay and of fish >4.6 kg in Delaware Bay from 1976 to 1980 indicates that more fish were growing into this size range than were being removed, which would be expected if large numbers of several strong year classes were reaching age 8 or older during this time period.

Several lines of evidence suggest more than one year class contributed to the increase in abundance of large weakfish in the 1970's and 1980's. First, in Chesapeake Bay the number of citation-size fish >5 kg in 1980 was larger than the number of citation-size fish >1.8 kg in 1970. Similarly, in Delaware Bay the number of citation size fish >4.6 kg in 1986 was larger than the number of citation-size fish >1.4 kg in 1971 and 1972. If only one year class was involved, the number of fish surviving to older and larger sizes would decrease rather than increase. Second, the pattern in Delaware Bay—of increasing numbers of fish >4.6 kg from 1975 to 1980, with a decrease in 1981 and 1982 and then a second increase until 1986—suggests the contribution of more than one year class. Third, it is unlikely that the more than 1,300 fish >5.0 kg recorded in Delaware Bay in 1987 were solely from the late 1960's year classes, because they would then be 19–21 years old.

The factors which produced the large year classes and allowed large numbers of weakfish to survive to older ages are not clear. Joseph (1972) suggested reproductive failure as the cause of the low landings in the 1950's and 1960's, and thus increased reproductive output and recruitment in the late 1960's could have caused increased year-class strength. That there was a shift in recruitment appears to be corroborated by the fact that weakfish larvae were rare in Chesapeake Bay in the 1960's (Joseph, 1972); yet in 1971–73 Olney (1983) found them to be second in abundance only to the bay anchovy, *Anchoa mitchilli*. Such a large shift in recruitment should be reflected in juvenile indices. However, the index of juvenile weakfish abundance, based on trawl surveys of the York River, Virginia, from 1955 to 1982, showed only a small increase in abundance in 1968—one that did not exceed levels in the 1950's—a larger peak in 1970, and an extreme peak in 1980 (Mercer, 1985).

In addition to variable recruitment, there also may have been changes in adult natural mortality rates. Such fluctuations are not uncommon, although they are difficult to document (Vetter, 1988; Hilborn and Walters, 1992). Factors such as increased food availability, which would increase reproductive output (Houde, 1989), would also be expected to decrease adult natural mortality rates.

Future research is necessary to understand better fluctuations in year-class strength and interactions between weakfish and other species. Stock-wide mortality rates need to be estimated and weakfish migration needs to be understood better. It is especially important that ages be based on sectioned otoliths—a validated ageing technique—so that future estimates of growth parameters, mortality, and longevity can be better compared over time and space.

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